Consistent VLBI, GPS and SLR Time Series of Station Positions and Troposphere Parameters

Böckmann S. (1), Artz T. (1), König R. (2), Müller H. (3), Nothnagel A. (1), Panafidina N. (2), Steigenberger P. (2, 4), Thaller D. (2), Tesmer V. (3)

(1) Institut für Geodäsie und Geoinformation Universität Bonn, IGG

(2) GeoForschungsZentrum Potsdam, GFZ

(3) Deutsches Geodätisches Forschungsinstitut, DGFI

(4) Institut für Astronomische und Physikalische Geodäsie, Technische Universität München

1. Introduction

A critical issue when comparing and especially combining parameters of different space-geodetic techniques are systematic differences between the a priori models and the parameterisation of different software packages, as this can lead to a misinterpretation of the combined results. Within the Geotechnologien project »GGOS-D«, a detailed adaption of different software packages has been performed and GPS, SLR and VLBI data have been reprocessed consistently for the complete time span. As a result, consistent time series of station positions from the GPS, SLR and VLBI data as well as time series of troposphere parameters from GPS and VLBI have been calculated. Co-location stations of at least two techniques have been used to compare the different time series in order to detect systematic or episodic signals.

2. Data processing

The GPS processing was carried out with the Bernese GPS Software 5.0 (Dach et al. 2007) at GeoForschungsZentrum Potsdam (GFZ), using data from 1994 to 2007. The VLBI sessions between 1984 and 2007 were analysed independently with two different VLBI analysis software packages: At the Deutsches Geodätisches Forschunginstitut (DGFI), München, the OCCAM v6.0 software package (Titov et al. 2004) was used, the Calc/Solve software (Petrov 2002) at the Institut für Geodäsie und Geoinformation (IGG), Universität Bonn. Similar to the VLBI analysis, two different SLR software packages EPOS and DOGS were used at GFZ and DGFI to process the SLR observations between 1984 and 2007.

Identical models for solid earth tides, pole tide, ocean loading, nutation and subdaily EOP variations, as well as the same a priori Earth orientation parameters, tropospheric a priori zenith delays and mapping functions have been used in all analysis software packages. Furthermore, the parameterisation of all common parameters is identical. The GPS and VLBI station positions have been estimated as daily and session-wise solutions, while the SLR station positions have been calculated weekly. In order to define the datum in the GPS and VLBI analysis, no-net-rotation (NNR) and no-net-translation (NNT) conditions with respect to IGS05 (for GPS, geocenter estimated) and ITRF2005 (for VLBI) were applied. SLR station positions have been computed by applying NNR conditions with respect to ITRF2005.

The tropospheric path delay ΔL is represented as a function of elevation angle ε and azimuth α of the vector between the ground station and the observed GPS satellite or quasar. The azimuth-independent part of the neutral atmosphere around a station is described as a sum of a zenith hydrostatic delay (ZHD) L_h and a zenith wet delay (ZWD) L_w (Eq. 1). For an observation with elevation angle ε both zenith delays are mapped using the Vienna Mapping Functions (VMF1, Boehm et al. 2006). The azimuth dependency of the tropospheric delay of the observation is considered with coefficients for gradients in north-south (G_n) and east-west direction (G_e), mapped with the gradient mapping function $m_g(\varepsilon)$ to the elevation of the observation.

$$\Delta L(\alpha, \varepsilon) = \Delta L h_h m_h(\varepsilon) + \Delta L_w m_w(\varepsilon) + m_g(\varepsilon) \times [G_n \cos(\alpha) + G_e \sin(\alpha)] \quad (1)$$

While for each GPS and VLBI station, the ZHD is corrected a priori (with interpolated ECMWF grid data), the ZWD is estimated in the least-squares adjustment. However, the estimated part cannot be completely interpreted as the real wet delay since it is also affected by the miscorrected part of the ZHD. For the gradient mapping function the simple equation by MacMillan (1995) with the wet mapping function has been used (Eq. 2)

$$m_g(\varepsilon) = m_w \cdot \cot(\varepsilon) \quad (2)$$

The troposphere zenith delay parameters are estimated as piece-wise linear functions for each station with a temporal resolution of one hour for VLBI and of only two hours for GPS, as the number of parameters in the GPS processing is much higher. The GPS-derived gradients are estimated for each site once per day as linear function. In the VLBI solutions the gradients are estimated as linear function for each 24 h-session. A priori values for the gradients are zero.

In contrast to GPS, the VLBI-derived troposphere zenith delay parameters and gradients could not be estimated completely free, due to the poor observing geometry of some VLBI sessions, especially the older ones: the rate of the troposphere zenith delay parameters had to be constrained to zero with a standard deviation of 1cm/hour while the troposphere gradients were constrained to zero with standard deviations of 2.5 mm and 5 mm/day. To be able to better compare the VLBI- and the GPS-derived troposphere parameters, both were always referred to intervals of full UTC hours, which is not typical for the VLBI-only solutions. The GPS troposphere parameters have been estimated from weekly solutions providing continuous results over a one week period, the VLBI-derived parameters do not provide such continuity, as there are only about 3–4 sessions per week with changing observing networks.

3. Comparison of station position and troposphere parameter time series

3.1. Station position time series

Figure 1 shows the temporal evolution of the GPS and VLBI height component of station

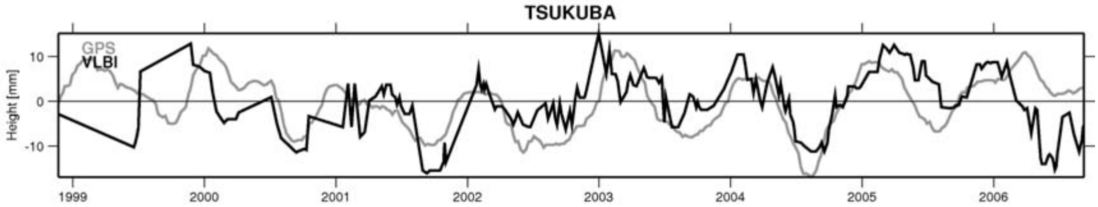

Figure 1: GPS and VLBI time series of Tsukuba height component (daily estimates, smoothed with a 70 days median filter computed each 7 days)

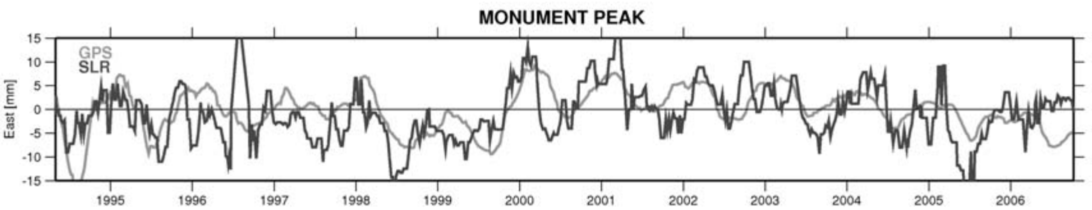

Figure 2: GPS and SLR time series of Monument Peak east component (GPS daily estimates, SLR weekly, both smoothed with a 70 days median filter computed every seven days)

Tsukuba in Japan (with offset and a trend removed from each time series). The GPS and VLBI results follow a very similar pattern with annual variations which may be linked to periodic ground water extraction (Munekane et al. 2004). Figure 2 illustrates the east component of the SLR-GPS co-location station Monument Peak. Although these two examples show a good agreement between series of different techniques, this is not the case for all stations.

3.2. Troposphere parameter time series

The comparisons of the estimated zenith wet path delays from GPS and VLBI show a very good agreement with correlations larger than 0.9.

The GPS and VLBI time series of the ZWD estimates as well as their differences for Hartebeesthoek are displayed in Figure 3. The differences show an offset of 5 mm with a standard deviation of 1 mm and a weighted RMS of 8 mm after removing the offset. In addition, a seasonal pattern is visible in the differences. In summertime, when the water content of the atmosphere as well as the variability is larger, the ZWD differences show a larger scatter (see Steigenberger et al. 2007).

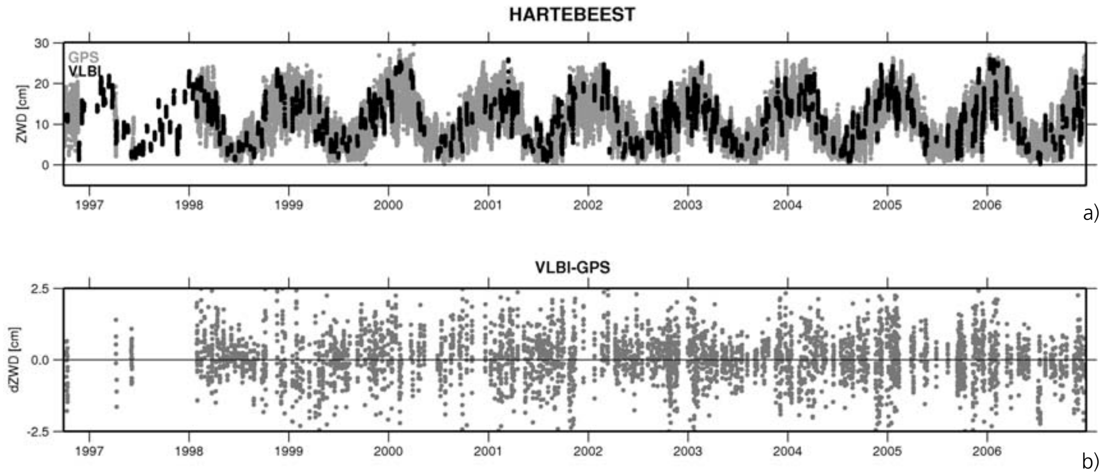

Figure 3: (a) Time series of zenith wet delays for GPS and VLBI, (b) differences of the series (VLBI minus GPS)

Figure 4: Time series of GPS and VLBI north gradients of Ny-Alesund (smoothed with 35 day median filter)

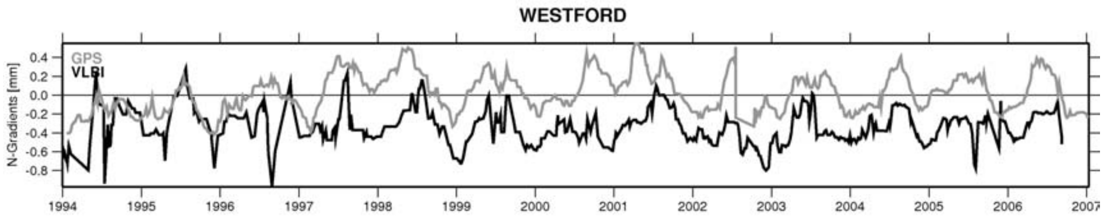

Figure 5: Time series of GPS and VLBI north gradients of Westford (smoothed with 35 day median filter)

Beside the zenith wet delays, the tropospheric horizontal gradients from GPS and VLBI can also be compared. Figures 4 and 5 illustrate the temporal variations of the north gradient from both techniques for Ny-Ålesund and Westford. While the gradients agree very well for Ny-Ålesund, the time series for Westford have a similar episodic behavior, but are offset by about 0.2 mm.
The reason for this offset might be the constraints on the a priori values (see Sec. 3) for the gradients determined by VLBI as also discussed in (Steigenberger et al. 2007). Another possibility might be due to correlations of the tropospheric horizontal gradients with the horizontal components of the station coordinates (MacMillian 1995, Krügel 2007).

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